

SELECTED TOPICS In Aerospace Engineering

EDITOR

ERWIN SULAEMAN



IIUM Press

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

SELECTED TOPICS In Aerospace Engineering

EDITOR

ERWIN SULAEMAN



IIUM Press

Published by:
IIUM Press
International Islamic University Malaysia

First Edition, 2011
©IIUM Press, IIUM

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without any prior written permission of the publisher.

Perpustakaan Negara Malaysia

Cataloguing-in-Publication Data

ISBN: 978-967-418-145-1

Member of Majlis Penerbitan Ilmiah Malaysia – MAPIM
(Malaysian Scholarly Publishing Council)

Printed by :
IIUM PRINTING SDN.BHD.
No. 1, Jalan Industri Batu Caves 1/3
Taman Perindustrian Batu Caves
Batu Caves Centre Point
68100 Batu Caves
Selangor Darul Ehsan
Tel: **+603-6188 1542 / 44 / 45** Fax: **+603-6188 1543**
EMAIL: iiumprinting@yahoo.com

TABLE OF CONTENT

PREFACE.....	i
TABLE OF CONTENT.....	iii
CONTRIBUTING AUTHORS.....	xiii

PART I

FUNDAMENTAL COMPRESSOR FOR AIRCRAFT'S TURBO ENGINES

1

NOMENCLATURE.

2

CHAPTER ONE

INTRODUCTION TO COMPRESSORS.

4

1.1 Introduction

4

1.2 Types of Compressors

4

1.2.1 Positive Displacement Compressors

4

1.2.2 Dynamic Compressors

4

1.3 Comparison of Compressor Types

5

1.3.1 Flow rate

5

1.3.2 Efficiency

6

1.3.3 Pressure Ratio

7

1.3.4 Characteristic Curves

7

CHAPTER TWO

<i>TWO-DIMENSIONAL ANALYSIS OF COMPRESSORS.</i>	9
2.1 Velocity diagrams of the compressor stage	10
2.2 Thermodynamics of the compressor stage	10
2.3 Stage loss and efficiency	11
2.4 Reaction ratio	12
2.5 Stage loading	13

CHAPTER THREE

<i>THREE-DIMENSIONAL ANALYSIS OF COMPRESSORS.</i>	15
3.1 Theory of radial equilibrium	15
3.2 Free-vortex flow	16
3.3 Forced vortex	18
3.4 General whirl distribution	18

CHAPTER FOUR

<i>ROTATING STALL AND SURGE.</i>	20
4.1 Performance of Axial and Radial Compressors	20
4.2 Aerodynamic Flow Instabilities	22
4.2.1 Rotating stall	23
4.2.2 Surge	24
4.2.3 Rotating Stall and Surge in Radial Compressors	26

CHAPTER FIVE

<i>MODELING OF COMPRESSION SYSTEMS.</i>	27
5.1 Introduction	27
5.2 Greitzer lumped parameter model	28

CHAPTER SIX

<i>COMPRESSOR MODELS.</i>	34
----------------------------------	-----------

6.1	Moore Model	34
6.2	Moore-Greitzer model	36

CHAPTER SEVEN

SURGE AND ROTATING STALL.

7.1	Stability of compression systems	40
7.2	Control of Surge and Rotating Stall	41
7.3	Avoidance Control	41
7.4	Active Control	44

REFERENCE OF PART I.

PART II

RIGID-BODY DYNAMICS OF AIR VEHICLE

CHAPTER EIGHT

AIRCRAFT RIGID-BODY EQUATION OF MOTIONS: A NONLINEAR MODEL

8.1	Introduction	49
8.2	Definition of Axes and Angles	49
8.3	The Rigid-Body Equations	52
8.4	Conclusions	55

CHAPTER NINE

AIRCRAFT EQUATIONS OF MOTIONS: A NONLINEAR MODEL

9.1	Introduction	57
9.2	Orientation and Position of the Airplane	57
9.3	Euler's Equations of Motion	59
9.4	Effect of Spinning Rotors	60
9.5	The Collected Equations	61

CHAPTER TEN***AIRCRAFT EQUATIONS OF MOTION: A LINEAR MODEL***

10.1 Introduction	63
10.2 The Small-Disturbance Theory	63
10.3 Conclusions	69
<i>REFERENCE OF PART II</i>	70

PART III***DYNAMICS OF FLEXIBLE STRUCTURE OF AIR VEHICLE***

71

NOMENCLATURES

72

CHAPTER ELEVEN***OVERVIEW OF DYNAMICS OF FLEXIBLE AIR VEHICLE***

76

11.1 Introduction	76
11.2 The Influence of the Structural Flexibility on Vehicle Design	76
11.3 Non-uniform Beam Finite Element	77
11.4 Aerodynamic Discrete Element Methods	79
11.5 The doublet lattice method (DLM)	79
11.6 The doublet point method (DPM)	80
11.7 Conclusions	81

CHAPTER TWELVE***TRANSLATION OF AXIS PROCEDURE TO CONSTRUCT STIFFNESS MATRIX***

12.1 Introduction	83
12.2 Static Equivalence Translation	83
12.3 Kinematic Equivalence Translation	84

12.4 Stiffness Matrix Construction	85
12.5 Conclusion	87

CHAPTER THIRTEEN

MINIMUM DENOMINATOR OF RATIONAL FUNCTION

13.1 Introduction	88
13.2 Rational Function Transformation	88
13.3 MDRF Procedure for Non-linear Variation of the Stiffness Distribution	89
13.4 Direct Differentiation Method	90
13.5 Substitution Procedure	91
13.6 Conclusion	93

CHAPTER FOURTEEN

TORSIONAL STIFFNESS MATRIX OF NON-PRISMATIC BEAM ELEMENTS

14.1 Introduction	94
14.2 Torsional - Twist Deformation Relation	94
14.3 Deformation of the Cantilever Bar Problem	95
14.4 Flexibility Matrix of the Cantilever Bar	97
14.5 Stiffness Matrix	97
14.6 Conclusion	98

CHAPTER FIFTEEN

BENDING STIFFNESS MATRIX OF NON-PRISMATIC BEAM ELEMENTS

15.1 Introduction	99
15.2 Load - Displacement Relation	99
15.3 Displacement of a Cantilever Bar Problem	100
15.4 Flexibility Matrix of the Cantilever Beam	103
15.5 Stiffness Matrix	104
15.6 Conclusion	104

CHAPTER SIXTEEN

FORMULATION OF KERNEL FUNCTION FOR AERODYNAMIC LOADING ON AIR VEHICLE

16.1 Introduction	105
16.2 Formulations of the Kernel Function	105
16.3 The formulation of Watkins, Runyan and Woolston	106
16.4 Formulations of Laschka	107
16.5 Formulations of Yates	109
16.6 Formulations of Landahl	109
16.7 Conclusion	110

CHAPTER SEVENTEEN

UNSTEADY AERODYNAMIC THEORY OF LIFTING SURFACE

17.1 Introduction	111
17.2 Assumptions	111
17.3 Basic Concept	111
17.4 Boundary Conditions	113
17.5 Kernel Function	113
17.6 Incomplete Cylindrical Function	115
17.7 Conclusion	115

CHAPTER EIGHTEEN

NUMERICAL EVALUATIONS OF HYPERGEOMETRIC CYLINDRICAL FUNCTIONS

18.1 Introduction	117
18.2 Kernel Integral Function	117
18.3 Modified Bessel Function of the First Kind of Order 0	118
18.4 Modified Bessel Function of the First Kind of Order 1	119
18.5 Modified Bessel Function of the Second Kind of Order 0	120
18.6 Modified Bessel Function of the Second Kind of Order 1	121
18.7 Modified Struve Function	121
18.8 Conclusion	122

CHAPTER NINETEEN

***ANALYTICAL DERIVATION OF THE INCOMPLETE
CYLINDRICAL FUNCTIONS: REAL PARTS***

19.1 Introduction	123
19.2 The finite subinterval of the integral	123
19.3 The Infinite Subinterval of the Integral	125
19.4 Conclusion	129

CHAPTER TWENTY

***ANALYTICAL DERIVATION OF THE INCOMPLETE
CYLINDRICAL FUNCTIONS: IMAGINARY PARTS***

20.1 Introduction	130
20.2 The finite subinterval of the integral	130
20.3 The Infinite Subinterval of the Integral	132
20.4 Conclusion	134

CHAPTER TWENTY ONE

***ALTERNATE EXPANSION SERIES FOR THE INCOMPLETE
CYLINDRICAL FUNCTION***

21.1 Introduction	135
21.2 Separation of Real and Imaginary Functions	135
21.3 Separation of Regular and Singular Functions	138
21.4 Conclusion	139

CHAPTER TWENTY TWO

***EXPANSION SERIES OF CONTINUOUS FUNCTION USING
ANALYTICAL INTEGRATION OF
LEAST SQUARE REGRESSION***

22.1 Introduction	140
-------------------	-----

22.2 Taylor and Maclaurin expansion series	140
22.3 Present Least Square Expansion Series	141
22.4 Application of the Present Approach to the Incomplete Cylindrical Function	143
22.4 Conclusion	145

CHAPTER TWENTY THREE

ALTERNATE APPROXIMATE FUNCTION FOR KERNEL

FUNCTION OF PLANAR OSCILLATING LIFTING SURFACES

23.1 Introduction	146
23.2 Epstein's Approach	146
23.3 Present Approach for Near Field Region	147
23.4 Present Approach for Middle Field Region	150
23.5 Present Approach for Far Field Region	151
23.6 Conclusion	151

CHAPTER TWENTY FOUR

APPROXIMATE FUNCTION FOR NEAR-FIELD KERNEL

FUNCTION OF NON-PLANAR LIFTING SURFACES

24.1 Introduction	152
24.2 Kernel Function Equation	152
24.3 Present Approximate Function	154
24.4 Conclusion	157

CHAPTER TWENTY FIVE

APPROXIMATE FUNCTION FOR FAR-FIELD KERNEL

FUNCTION OF OSCILLATING NON-PLANAR LIFTING SURFACES

25.1 Introduction	158
25.2 Landahl's Kernel Function Equation	158
25.3 Present Kernel Function Formulation	159
25.4 Conclusion	161

CHAPTER TWENTY SIX

IMPROVED VORTEX LATTICE METHOD

26.1 Introduction	162
26.2 Present Vortex Lattice Method	162
26.3 Conclusion	167

CHAPTER TWENTY SEVEN

IMPROVED DOUBLET POINT METHOD

27.1 Introduction	168
27.2 Present DPM for Planar Lifting Surfaces	168
27.3 Present DPM for Non-Planar Lifting Surfaces	170
27.4 Conclusion	174

CHAPTER TWENTY EIGHT

IMPROVED DOUBLET LATTICE METHOD

28.1 Introduction	176
28.2 Present DLM for Planar Lifting Surfaces	176
28.3 Conclusion	179

CHAPTER TWENTY NINE

APPLICATION OF THE AERODYNAMIC DISCRETE ELEMENT METHODS

29.1 Introduction	180
29.2 Delta Wing with $AR=2$	180
29.3 Cropped-Double-Delta Wing	182
29.4 Sweptback Wing with Partial Flap	183
29.5 AGARD Wing-Horizontal Tail	184
29.6 Conclusion	186

CHAPTER THIRTY

AEROELASTIC STABILITY PROBLEM OF AIR VEHICLE

30.1 Introduction	187
-------------------	-----

30.2 The Flutter Solution Method	187
30.3 Validation of the present flutter procedure	191
30.4 Conclusion	193
<i>REFERENCES OF PART III</i>	195

*NUMERICAL EVALUATIONS OF HYPERGEOMETRIC
CYLINDRICAL FUNCTIONS*

18.1. Introduction

Evaluation of hyper-geometric transcendental functions occurring in the formulation of the kernel function of unsteady aerodynamic load is described in this chapter. The hypergeometric functions is known also as complete cylindrical functions in the forms of modified Bessel functions and Struve functions. Accurate and efficient evaluations of these functions are required in order to improve the robustness and accuracy of the aerodynamic load simulation

18.2. Kernel Integral Function

The calculation of the kernel function requires evaluations of several integral forms that may be classified into two types:

Type A
$$B_n = \frac{i_n}{r^2} = \frac{1}{r^2} \int_{-\infty}^X \frac{e^{iku}}{r (1+u^2)^{n+\frac{1}{2}}} du \quad (18.1a)$$

where the lateral distance r is not involved in the algebraic part of the integrand

Type B
$$B_n = \frac{1}{r^2} \int_{-\infty}^X \frac{e^{iku}}{(r^2+u^2)^{n+\frac{1}{2}}} du \quad (18.1b)$$

where the lateral distance r is included in the integrand

To solve the integral problem above it is customary to divide the interval of the integration into two sub-intervals $[-\infty, 0]$ and $[0, X]$ as follow

$$B_n = \frac{1}{r^2} \int_{-\infty}^0 \frac{e^{iku}}{(r^2+u^2)^{n+\frac{1}{2}}} du + \frac{1}{r^2} \int_0^X \frac{e^{iku}}{(r^2+u^2)^{n+\frac{1}{2}}} du = B_n(0, \infty) + B_n(0, X) \quad (18.2)$$